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On L–C–R and rectification properties of anodic ZnO thin film

Tapan Sengupta

Department of Physics,
Ranaghat College, Nadia-741 201, West Bengal, India

Abstract : The experiment was originally aimed to get an understanding of the self-recovery microwave receiver (coherer) designed by Sir J C Bose in 1894. It is now well-understood that the simple soft touching metal-metal contact certainly worked as an M O M diode with an inbuilt L-C-R circuit. In this work, thin polycrystalline film of anodic ZnO was deposited on metallic Zn pellets. Depending on the condition of anodization N-type (white) or P-type (black) coloured oxides could be deposited. The barrier heights were found to be independant of the work functions of the contacting metal probes indicating the presence of a large number of interface states. The L-C-R behaviour was also analysed. Here, the actual current values could be divided into inductive and capacitative contributions by trial and error method (simulation). The slow changes of L and C when subjected to 1 volt A.C. input by using a direct reading L-C-R meter were recorded and it was found that the L-C product remained more or less unchanged

Keywords : Oxide thin film, rectification, L-C-R behaviour

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1. Introduction

Early detector of electromagnetic waves was made by H. Hertz in 1887. Later on Sir O. Lodge [1] used metallic filings of iron or nickel in a glass cylinder pressed loosely by two metal pistons from which two electrical leads were taken. As soon as electromagnetic waves from a nereby source fell on it, the metal filings permanently switched over to a low resistant state (probably due to cohering of the metal filings). This receiver required to be tapped, either by fingers or electromagnetic relay system. In order to reduce the no. of parameters of the experiment, Sir J. C. Bose [1] used an iron cat's whisker lightly touching a convex iron surface. This receiver had a very novel characteristics, that it required no tapping to make it ready for the reception of a new wave and so it was termed as self-recovery coherer. Above all, with the use of waveguide (unknown till then), Bose succeeded to detect micro waves from a source ~ 100 metres away. It is now known that the deviation from stoichiometry is the origin of semiconducting properties of metal-oxides. In the present experiment, a thin layer of white anodic ZnO (N-type) was used. Barrier heights were determined by using modified Cooper's method (2, 3). Indication of damped oscillatory behaviour of a potassium – cadmium contact when subjected to D.C. voltage stresses, was observed by Chatterjee and Sen (4).

2. Experimental

Thin film of white ZnO was deposited on Zn plates (99.99% pure) in an alkalline bath containing 2% NaOH solution, anodizing current remaining about 200 milli amperes. The detailed experimental procedure has been discussed elsewhere (3, 5).

3. Result and discussion

Figures 1–3 represent the nature of current variation with time when the contact was subjected to 7.5 volt forward bias at three arbitrary pressures, P_1, P_2, P_3 respectively ($P_1 > P_2 > P_3$). Figure 4 represents the actual circuit diagram while the proposed

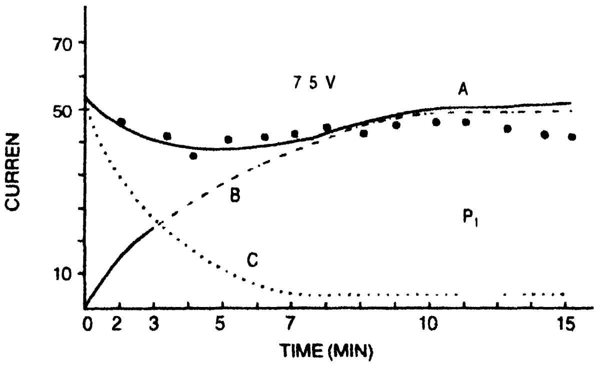

Figure 1. Current variation with time.

equivalent circuit is shown in Figure 5. In both the figures, V.S and XY are voltage source and pen-recorder (or milli-ammeter) connections. In Figure 5, R represents the effective spreading

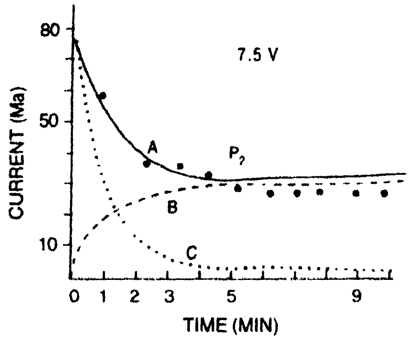

Figure 2. Current variation with time

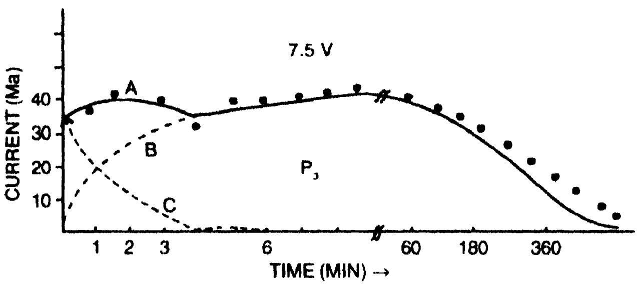

Figure 3. Current variation with time

resistance, and D, the single-grain Schottky type diode with negligible bulk resistance. L and C are equivalent inductance and capacitance respectively. The origin of L and C are most probably due to slow traps or trap clusters (5–10). A capacitance C' of very high value with time constant of few hours has to be inducted in the circuit, as it has been observed that if the voltage injection time prolongs to 6 to 12 hours, the final current approaches near to zero. But during the first 15 minutes of run, its effect is very little. C', most probably comes into play due to long-hour adsorption from ambient atmosphere, which is the so called 'ageing' effect common to 'unsmart' semiconductors.

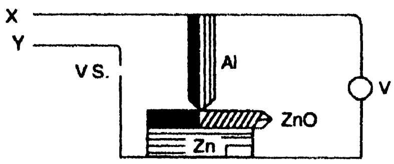

Figure 4. Actual circuit diagram.

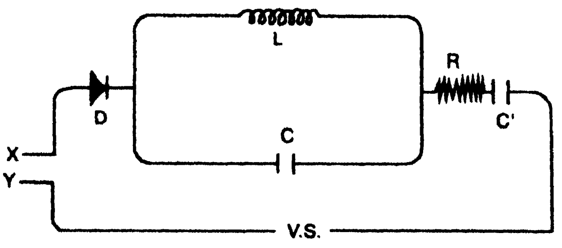

Figure 5. Proposed circuit diagram

In Figure 6, time variations of inductance and capacitance are measured by a direct reading L–C–R meter. The instrument works at 1 volt A.C. input. Here the junction-pressure was adjusted to yield low inductance and capacitance, so that the span was within the range of the measuring instrument. The figure is self explanatory. It is noteworthy that L.C product remains practically more or less constant during the run. At high frequency (1 kilo Hertz), L and C values under the identical junction conditions, are reduced drastically to about 20 milli Henry and 24 nano Farad respectively. The low values of L and C at high frequency are most probably due to the sluggish nature of slow interface and bulk traps. The loss factor D remained at ~ 4 during the runs.

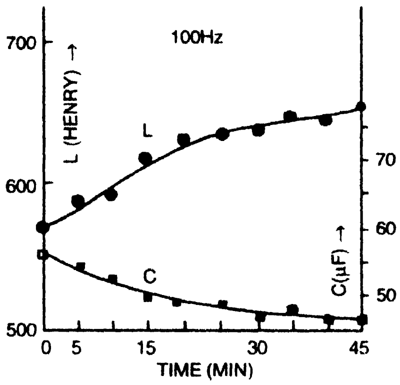

Figure 6. Variation of inductance and capacitance with time

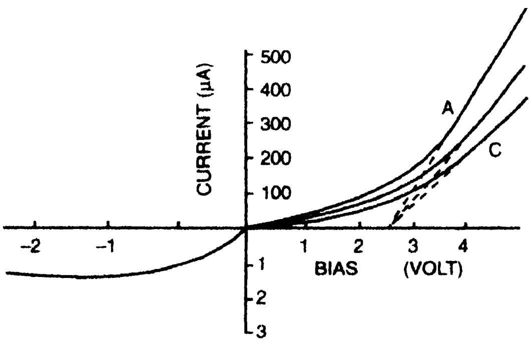

Figure 7. I–V characteristics

Figure 7 represents the I – V characteristics near the origin (using a Cambridge pen recorder polarograph). Since the grain size (~ 1 micron) was about 10 times larger than the thickness (~ . 1 micron) of the film, it may be assumed that there are a large number of single grains existing across the film. The scanning process most probably placed the probe-needle on such a single grain (single crystal). Now the I-V characteristics were taken with 0, 1 kilo Ohm, 2 kilo Ohms put in series with the contact (traces A, B, C respectively). The barrier height which was measured by using modified Cooper's method [2, 3, 5] was found to be ~ 2.5 ev. At high reverse voltages (not drawn) of ~ 12 volts the junction showed soft Zener-type breakdown [11].

Now to get an idea of the relative values of inductance and capacitance measured under D.C voltage, Figures 1,2,3, are reconsidered. The values of spreading resistances, measured from the steady current values were about 125, 250 and 200 Ohms in Figures 1,2,3 respectively. During the transient period, current flowing through R is expected to follow a formula of the type

$$I = I_0 + I_0 \left(e^{-t/\lambda} - e^{-t/\lambda'}\right) \text{ with}$$

$$\lambda = \mathrm{C.R} \text{ and } \lambda' = \mathrm{L/R}.$$

Now by using a computer programming, approximate numerical values of L and C can be obtained by using trial and error method so as to simulate or match the above equation. The B and C curves, for inductive growth and capacitative decay of current flowing through L and C parts of the equivalent circuit (Figure 5) have been drawn by using appropriately matched values of L and C, thus obtained. The curve A is obtained by adding B and C. The values of L have been computed to be about 0.375×10^5, 0.15×10^5 and 0.09×10^5 Henries respectively; similarly computed values of C were about 0.4, 0.24 and 0.3 Farads obtained for Figures 1, 2, 3 respectively. The close proximity of the computed curves with the experimental points justifies the presentation of the equivalent circuit.

4. Conclusion

Thus, the simple M–O–M diode is a complex combination of inductance, capacitance and resistance whose values can be adjusted by judicious manipulation of the contact position and pressure. Further research in this line, is in progress.

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